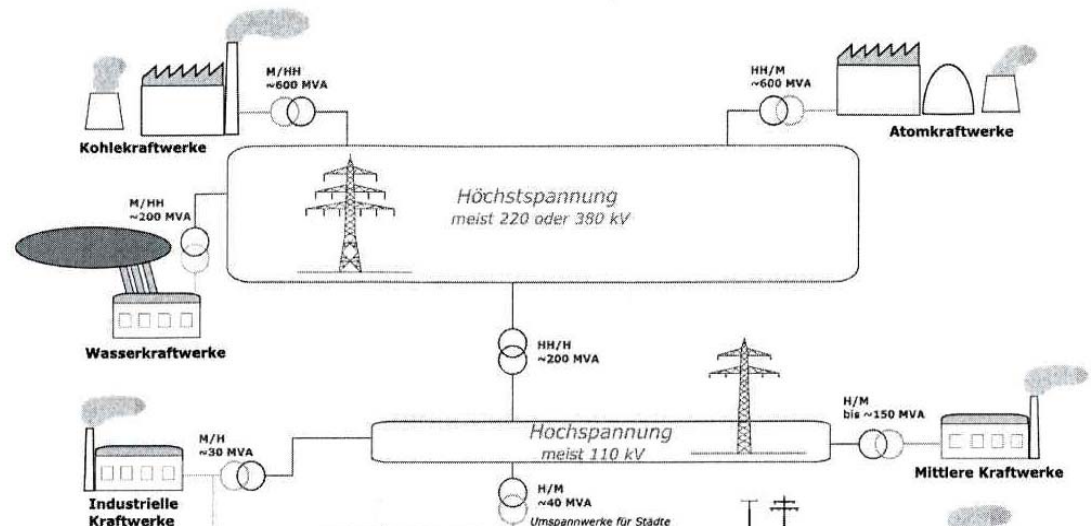




“Electricity finance”: Market fundamentals and price modeling

Stefan Schneider | E.ON Energy Trading - Quantitative Modeling / Asset Optimization | Lund, Oct 2012

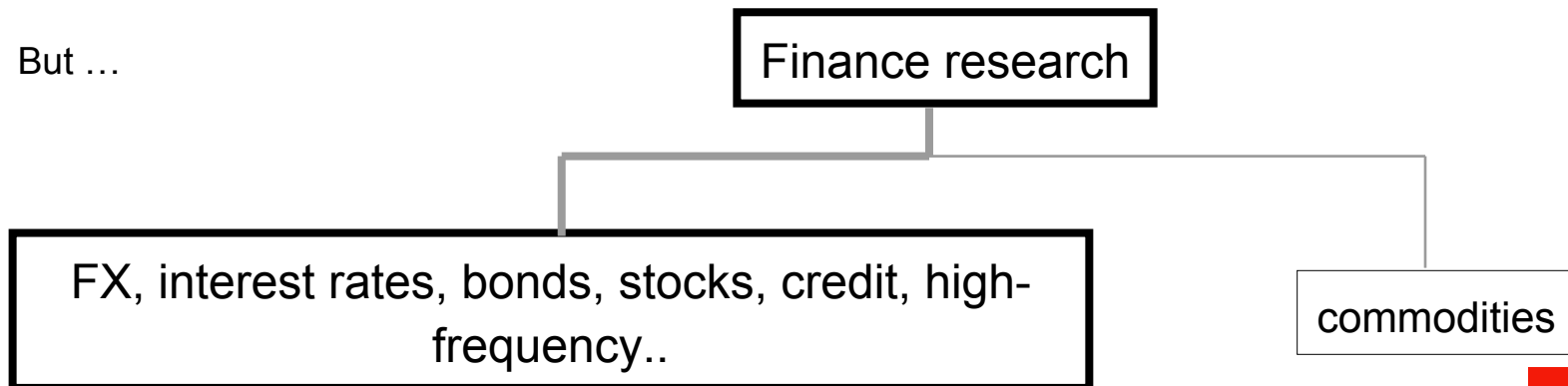
Energy/Commodity finance is (still) an exotic subject of Finance

Over the last 10-15 years commodities have been receiving much general attention

- This came with massive globalization and economic development in the non-Western world (BRIC states, ..)
- The world economy „runs on oil“. Also, coal, LNG and ore are shipped between the continents
- Strong development of agricultural (corn, soybeans, ..) trading (North and South America, ..)
- „Players“: privatized energy sector (E.ON, EDF, ..), banks (Deutsche Bank, ..), commodity companies (Glencore, Vitol, ...), hedge funds, states (China, ..), ..

→ Triggered build-up of commodities groups in finance research

But ...



Energy/Commodity finance is (still) an exotic subject of Finance

Commodities have not yet gained a share in finance research proportional to its share in world economics importance (consider the enormous volumes of crude oil bought and sold every day)

- Research done primarily in energy commodities: oil, gas, electricity, ..
- Hardly any publications for: agricultural commodities, base metals, ..

.. Independently of any research and publications, commodities are traded very actively and in large amounts. See exchange places like **NYMEX**, **CBOT**, .. (how does Deutsche Bank's in-house research on commodities look like?)

The reason for that praxis-theory gap seems to be that commodities exhibit „unwieldy“ behavior when approached with „classical finance theory“

- **Market incompleteness:** Vast arrays of products (must naturally) exist: oil grades, electricity consumption structures. Impossible to trade all those (proxies are often used for hedging)
- **Market imperfection** (limited **liquidity**). Deals done with much lower frequency than stocks, but much higher value per deal (consider an 300,000 ton iron ore ship)
- **Technical and regulatory constraints and risk factors:** Oil refinery co-produce products, volume and weather risk in electricity contracts/delivery

→ Markets quite different from stock markets (exception: gold)

Energy/Commodity finance is (still) an exotic subject of Finance

However .. Isn't it reasonable that general finance can take lessons from commodities?

- Market incompleteness: is a „standard“ in other fields, too: individual customer care, bespoke deals, structuring, ..
- Liquidity: has been discovered as a significant risk in with the credit crisis
- Regulatory / political risk: European debt crisis
- Model and hedge robustness (parameter risk)

Energy finance – on the other hand - is on the way to more bespoke methodology, instead of imitating banks' stocks finance (a kind of blue collar - white collar synergy)



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Electricity finance: Market fundamentals

Electricity is a commodity = a physical good to be produced and consumed

- Supply (electricity generation):
 - Power is mostly (for most countries and for most of the volume) a **multi-commodity / spread** business: e.g., consume coal and emission certificates to generate electricity
 - But also: hydro, nuclear, renewable (wind, solar)
- Demand (electricity consumption):
 - Little elasticity (insensitive to prices). Completely **inelastic** on a short time scale
 - Follows its pronounced natural consumption pattern (**periodicity/seasonality**): business hours, everyday life, weather, economical trends
- **Not storable** (as opposed to, e.g., oil). Production to be consumed instantaneously
→ the standard **spot-forward price relation does not hold** (as, e.g., for stocks)
- (Only large scale exception: Scandinavian hydro pump storages)

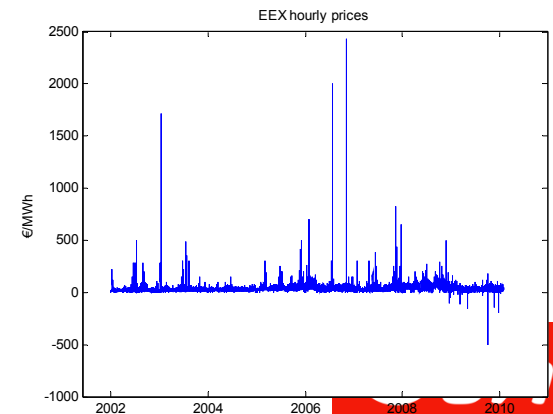
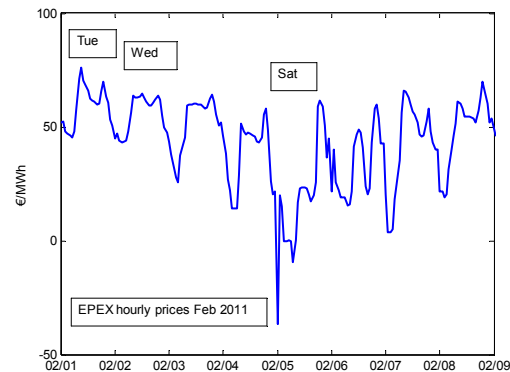
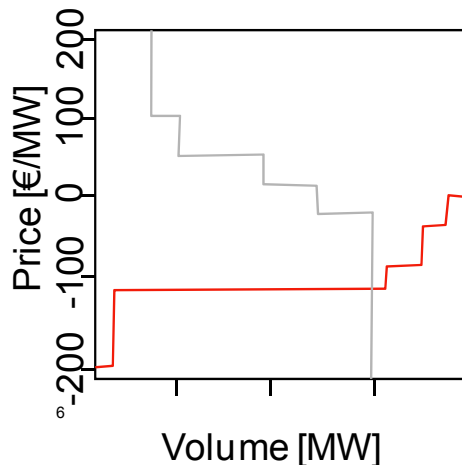


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Electricity finance: Market basics (financial)

The spot market – example **EPEX** (Germany, Netherlands, Belgium, France) for a typical European spot market (differing designs for, e.g., North America)

- Auction (day head consumption): participants submit bids and offers with respective volumes, auctioneer matches bid (supply) and offer (demand) stacks
- The **stack** reflects a large span of production modes and costs
 - **Base load** production (nuclear), costly **peak load** production (gas), almost costless renewable
 - Stack contains the “plants **merit order curve**”. Price setting plant = “**plant at the margin**”
- Non-storability & inelastic demand & technical constraints cause surprising (even extreme) price variability
 - (positive) **Spikes**: Generation is at the limit, very expensive production + scarcity premium
 - **Negative prices**: generation oversupply (e.g., extreme wind) & technical constraints



Electricity finance: Trading, products, derivatives

Trading / wholesale market (overlaps with retail) - energy companies, banks .. :

- standard **Futures**: actually period **swaps** of the underlying spot index , eg “base load 2013 10 MW”
- European options on futures
- **Tolling** : physical or financial contract about a “**virtual power plant**” ← **swing option on commodity spread**

Retail market (overlaps with wholesale) – municipal utilities, ..:

- **Structured future**: “**load schedule**” = hourly structured consumer profile, eg “Lund 2013”
- “**Open delivery**”: consumer can (and will) deviate from schedule = volume option. Option execution, however, is not optimal against power spot price, instead, risk factors are business needs, weather, consumer behavior (.. soccer world cup ..)

Market characteristics (see Introduction)

- High market incompleteness
 - Multitude of risk factors: volume (consumption), weather, plant availability, ..
7. A power plant or a consumer is in fact a complex derivative ..

Modelling electricity prices

There are 2 main routes to come up with stochastic (electricity) price models

- Recall the **swap** nature of electricity forwards (adds complication to the spot-forward relation)

Route 1: Start with the spot price

- Forwards and other derivatives by calculating risk-neutral expectation
- Lucia & Schwartz (2002): 2-factor model (no spikes yet)
- Benth et al (2007): Non-Gaussian Ornstein–Uhlenbeck processes (tackles the swap problem)
- De Jong (2006): **Regime switching** (spikes, German market)
- Green & Nossman (2008): **Jump diffusion, stochastic volatility** (spikes, Nordic market)
- Burger et al (2004), Coulon et al (2009): “**Hybrid**” models (incl further explanatory “**fundamentals**” of electricity generation)

Route 2: Start with a full forward curve model

- HJM type model. Spot price derived – e.g., by differentiation.
- Benth & Koekkebakker (2005) : Swap dynamics (find that route 1 is hard to go when aiming at detailed forward dynamics)
- Heider (2012): **Cointegration** of commodities prices, spread option (coal, gas, electricity)

Note the increasing “energy specify” over the last years.

Modelling electricity prices

Additional challenge: **Non-storability** of electricity -> **risk premiums** between expected spot and traded forward to be analyzed

- See, e.g., Benth, Cartea, Kiesel (2007)

In practice, a comprehensive modeling including both detailed spot as well as forward treatment is very intricate / not yet satisfyingly solved

- The spot price dynamics of electricity comprises a lot of technical short-term “idiosyncrasies”, which are hard to “indirectly imply” when going the forward route
- However, in forward models it is easier to deal with long-term idiosyncrasies (e.g., long-term co-integration equilibrium of fuels)

In practice, thus, both types of models are in operation in parallel

- Spot price models in case detailed spot values are required : **valuing a power plant’s generation** load schedule, ...
- Forward models: far maturity horizon, (standard) futures trading, **hedging** (spot specifics average out to some degree over long swap periods)
- Risk premiums are ad hoc / very simplified

Modelling electricity prices: spot

Here, I focus on the spot price route (being closer to the “technical foundations” of electricity prices)

What does an electricity spot price model has to capture:

- Pronounced **periodicity/seasonality** over day, week, year (following demand, production and weather patterns)
- **Mean reversion**: Price fluctuates around a „normal level“ (with periodicity/seasonality). Level follows the plant at the margin, given the seasonal demand
- **Spikes**: Sudden jumps to extraordinary prices. Can be **positive** as well as **negative**!
 - Note: Spikes do not mean-revert back to normal, they jump back

→ I discuss the approach of De Jong (2006), extended by Schneider (2011) ☺

An electricity spot price model accounting for spikes and negative prices

De Jong's (2006) price model (often referenced to because it is clear and practical)

- Stochastic process is for **daily prices** (only, because their stochastic is significantly simpler than hourly prices)
- Hourly prices – when needed for the valuation task at hand - are added in an „ad hoc“ fashion

Mean-reverting regime M:
$$dx_t^M = \alpha(\mu - x_{t-1}^M) + \sigma \cdot \varepsilon_t$$

Spike regimes:
$$x_t^S = \mu + \sum_{i=1}^{n_t+1} Z_{t,i}$$

High spike regime H:
$$Z_{t,i} \sim N(\mu^H, \sigma^H), \quad n_t \sim POI(\lambda^H), \quad \mu^H > 0$$

Low spike regime L:
$$Z_{t,i} \sim N(\mu^L, \sigma^L), \quad n_t \sim POI(\lambda^L), \quad \mu^L < 0$$

Markov transition matrix:
$$\Pi = \begin{bmatrix} 1 - \pi^{MH} - \pi^{ML} & \pi^{MH} & \pi^{ML} \\ \pi^{HM} & 1 - \pi^{HM} & 0 \\ \pi^{LM} & 0 & 1 - \pi^{LM} \end{bmatrix}$$

An electricity spot price model accounting for spikes and negative prices

Features

- **Regimes** = Multiple price processes
 - **normal price regime** = standard mean reverting process (to seasonal deterministic level)
 - **2 spike price regimes**: „**High**“ for an extraordinarily high price case, „**Low**“ for the opposite
- Switching between regimes = **Markov process** (with „spike“ an „return“ probabilities)
- Spike price process
 - Actually no real time series dynamics but just drawing from a distribution
 - **Poisson compound normal distributions** = makes the **fat tails**

Simplification makes **closed form solutions** for options possible

„Ad hoc“ extension by de Jong & Schneider: Hourly prices come in by appropriately sampling and transforming historical spot daily price profiles

- Not very satisfying, since not based on a comprehensive understanding of how hourly prices are brought about
- Not analytic / closed form

Current research deals with more sophisticated approaches for hourly prices, see below

An electricity spot price model accounting for spikes and negative prices

What to do about **negative prices**? The usual finance log transformation $p \rightarrow \ln(p)$ does not work

Observations:

- Prices are often around 0, above, as well as below
- Extraordinarily negative prices appear like inverted spikes (the „traditional“ upwards jumping spike)

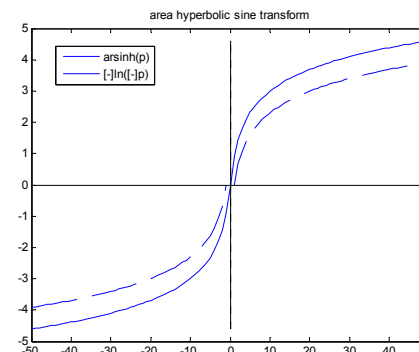
Conclusion: in contrast to, eg, stock prices, the electricity price is not „repelled“ by 0. In fact, the ≈ 0 region appears to belong to a normal price regime. Spikes can jump in both directions

Proposal (Schneider 2011): **area hyperbolic sine transformation** instead of log (ζ : offset , λ : scale)

- Natural extension of log - Same asymptotics as $(-)\ln[(-)p]$ for large $|p|$
- Deeper idea: Reflects the merit order feature of electricity production

→ It is still possible – similar to the log price case – to obtain **closed form solutions** for price distributions, forwards and European options

$$x = \sinh^{-1}\left(\frac{p - \xi}{\lambda}\right)$$

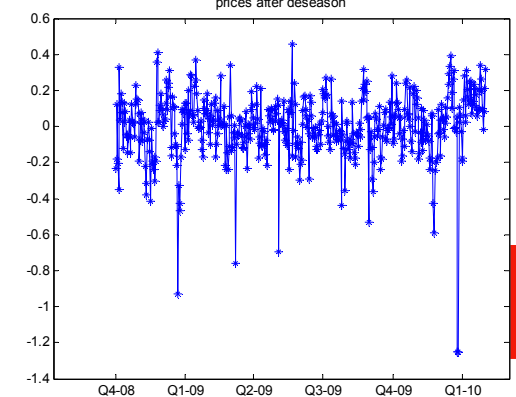
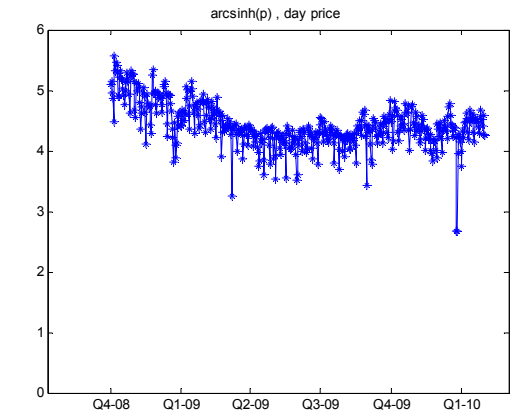
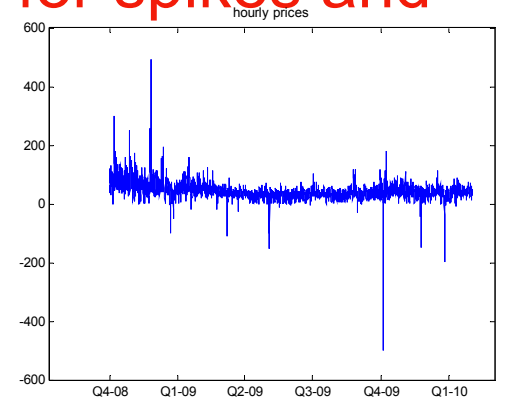


An electricity spot price model accounting for spikes and negative prices: Parameter estimation

Estimating parameters (the often underrated part of model design)

- Average hourly to daily prices (retain hourly profiles for later re-sampling)
- Remove periodic / seasonal and trend components (.. devil is in the details ..)
- (Complex) maximum likelihood estimation of stochastic parameters

Findings: Spikes are occasional and short lived (Markov probabilities)



Parameter estimates regime switch model (5b)

Time-series parameters:

Normal regime α	0.42
μ	0.02
σ	0.11
High-spike regim μ^H	0.35
σ^H	0.06
λ^H	0.10
Low-spike regim μ^L	0.24
σ^L	0.04
λ^L	2.00

Switch probabilities

from N to H	0.95%
from H to N	71.15%
from N to L	1.93%
from L to N	78.50%

An electricity spot price model accounting for spikes and negative prices: Simulation results

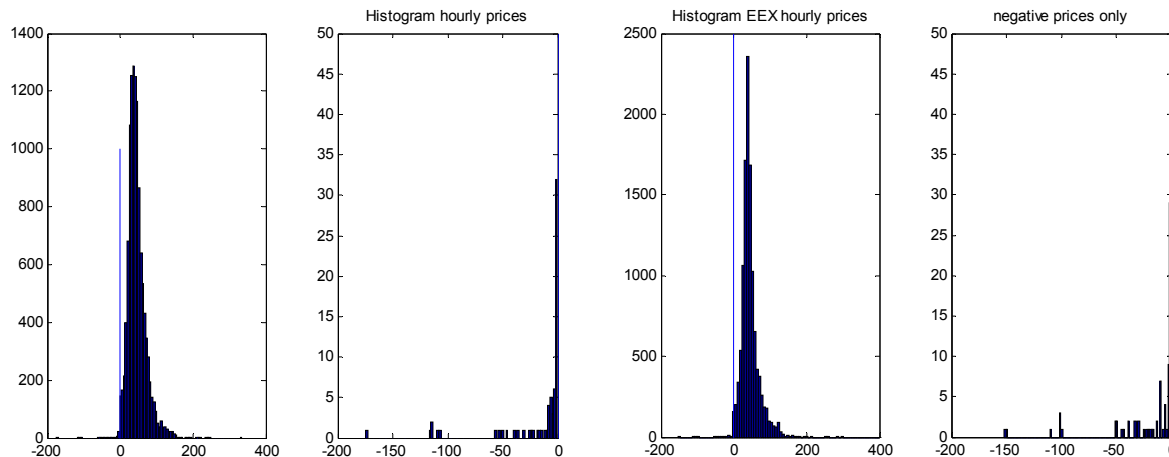
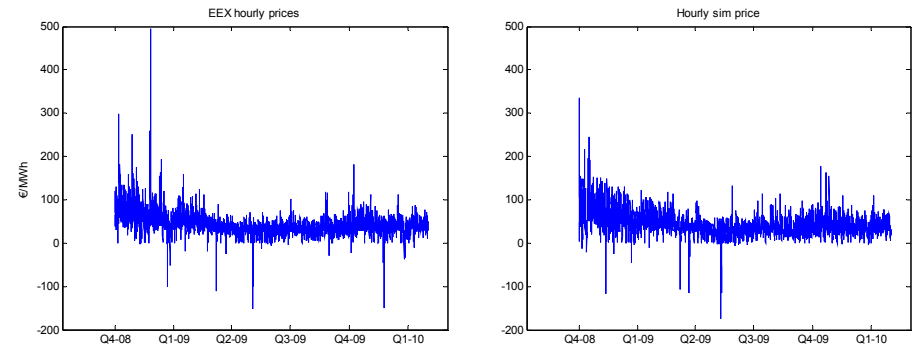
Simulation matches original reasonably well

Compare:

- Distribution properties: standard deviation, skewness and **kurtosis** captured?
- Sample trajectories: characteristics of dynamics captured?

Note the **fat tails** of the distributions

- Far beyond Gaussian
- Brought about by spike regimes



What else in electricity price modelling?

Jump diffusion, stochastic vol and regime switching perform much better than the first simple models

But what else is important?

- Spikes (and other electricity price characteristics) are driven by specific risk factors (which can be integrated into the modeling framework): weather, plant outages, oversupply, grid congestion, .. (see, e.g., Mount et al 2006)
- The more fundamental stochastic process is demand. Plant merit order + trading → price process: load & stack modeling (see, eg, survey of Coulon et al 2012)
- Hourly prices exhibit complicated relations beyond correlation. Typical plant dispatch patterns over the day „tie“ them together
- The electricity price is naturally closely tied to fuel prices (or hydro levels). Modeling co-integrated processes.
 - However, an essential feature for energy trading companies is the non-stationary of the spread (co-integration relation). This is where money can be made or lost, need to know for long-term investments

What comes next in electricity price modelling?

The recent years have shown that the electricity markets frequently undergo structural changes

- Emission reduction regulations
- Massive renewable generation build-up (wind, photovoltaic, biomass)
- „Market couplings“: coupled spot auctions for neighboring countries under (transmission) constraints (complex)
- Fuel price dependent plant park, long-term investment, real options. E.g., the slump of gas prices in the US (shale gas rally), plant park currently restructured to gas
- Economic cycles and trends (e.g., rise of China)

Since energy price models necessarily need to deliver values over a couple of years ahead, structural / regulatory / parameter risk / „forward looking information“ must be incorporated

- Currently, models are still too much relying on historical parameter estimation
- Hybrid models may cope with the task, as they contain parameters for structure (e.g., plant merit order)

This is possibly a challenge which can contribute to finance in general

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